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(54) **ELECTRODE MATERIAL FOR A SPARK PLUG**

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H01T 13/39 (2006.01)

(52) **U.S. Cl.**
CPC ***H01T 13/39*** (2013.01)

(58) **Field of Classification Search**
CPC H01T 13/39
USPC 313/141
See application file for complete search history.

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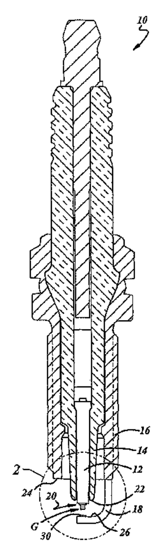
(57) **ABSTRACT**

An electrode material for use with spark plugs and other ignition devices. The electrode material is a two-phase composite material that includes a matrix component and a dispersed component embedded in the matrix component. In a preferred embodiment, the matrix component is a precious-metal based material and the dispersed component includes a material that exhibits a high melting point and a low work function such as, for example, carbides, nitrides, and/or intermetallics. A process for forming the electrode material into a spark plug electrode is also provided.

19 Claims, 7 Drawing Sheets



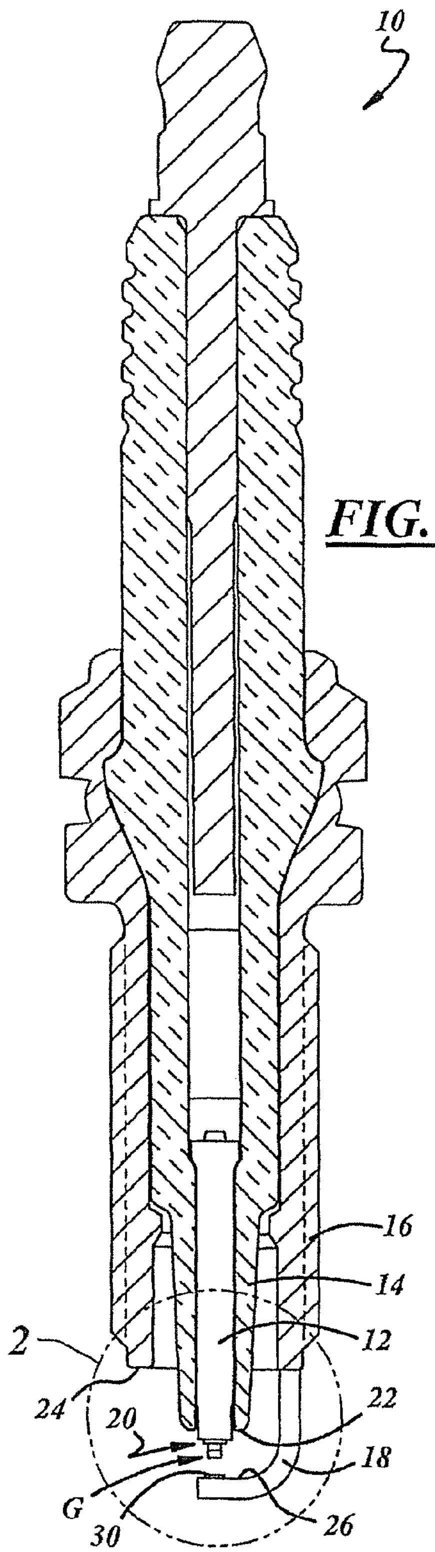


FIG. 1

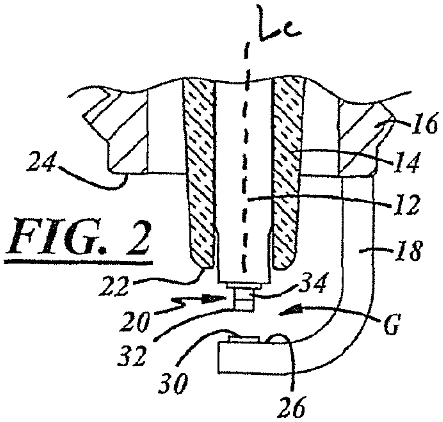


FIG. 2

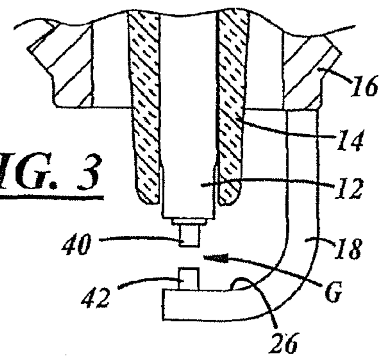


FIG. 3

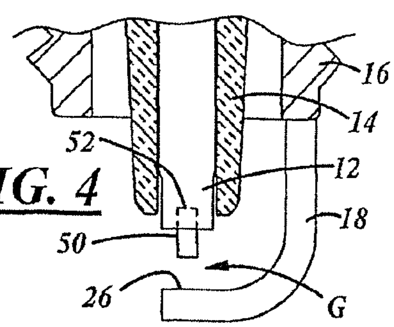


FIG. 4

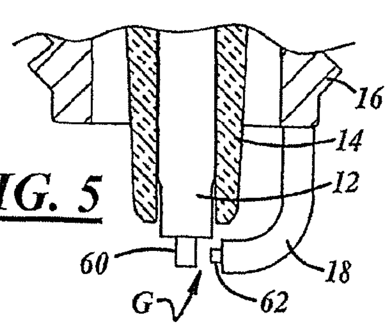


FIG. 5

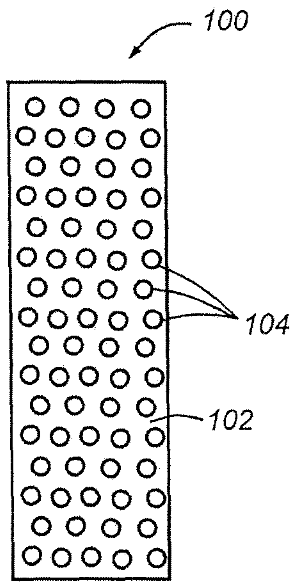


Figure 6

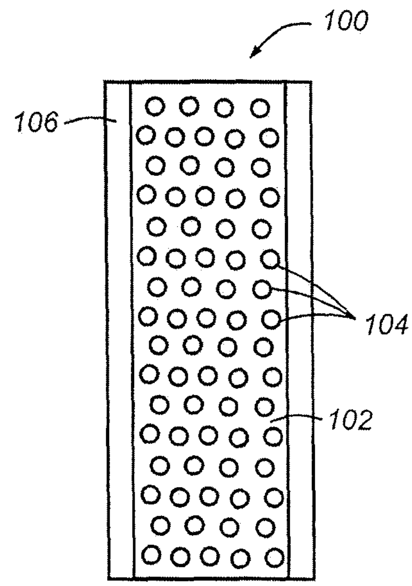


Figure 13

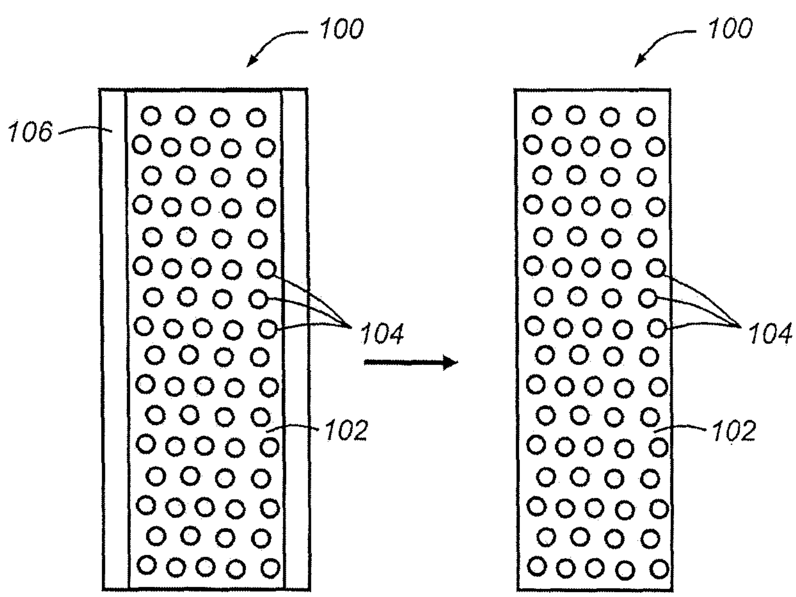
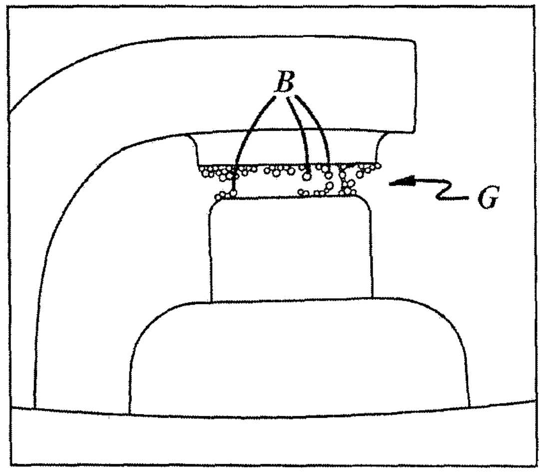


Figure 14

FIG. 7



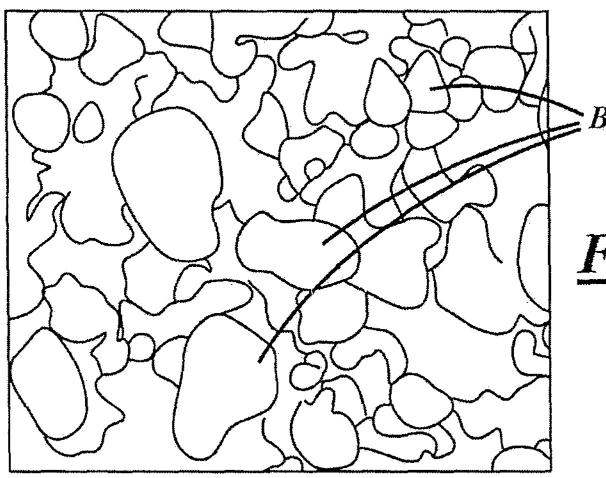
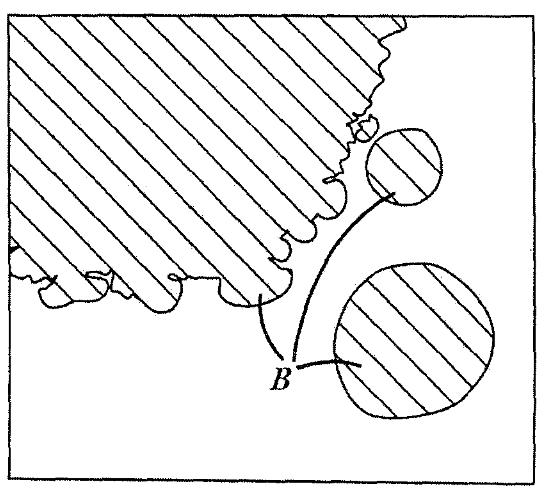


FIG. 8

FIG. 9



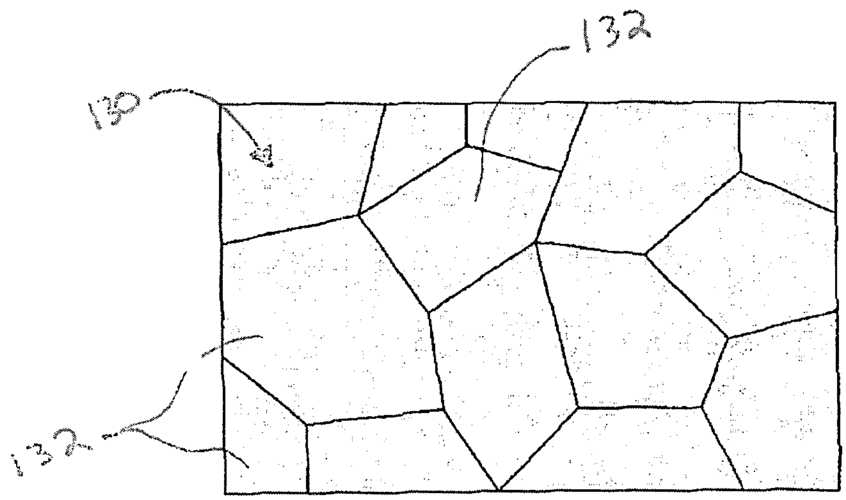


FIG. 10

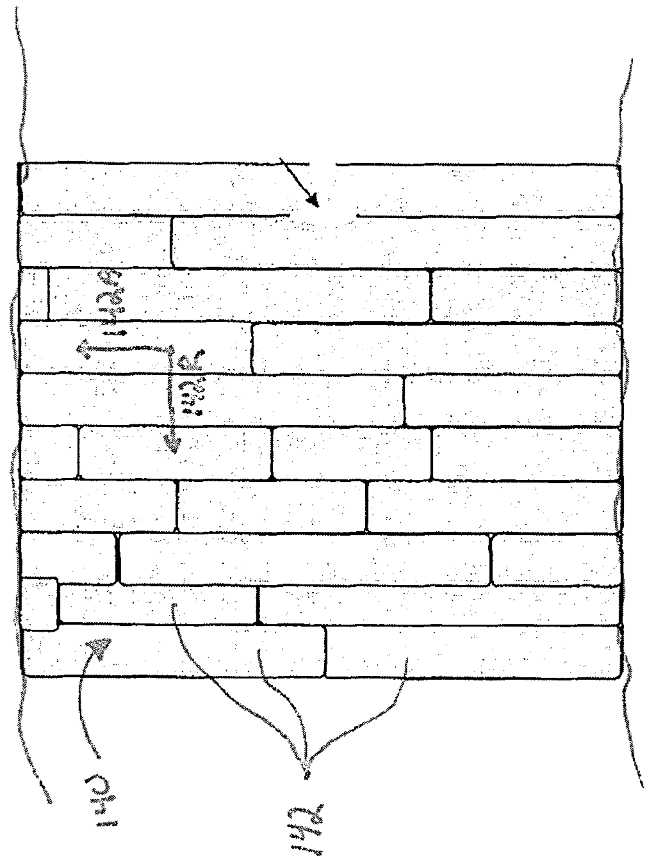


FIG. 11

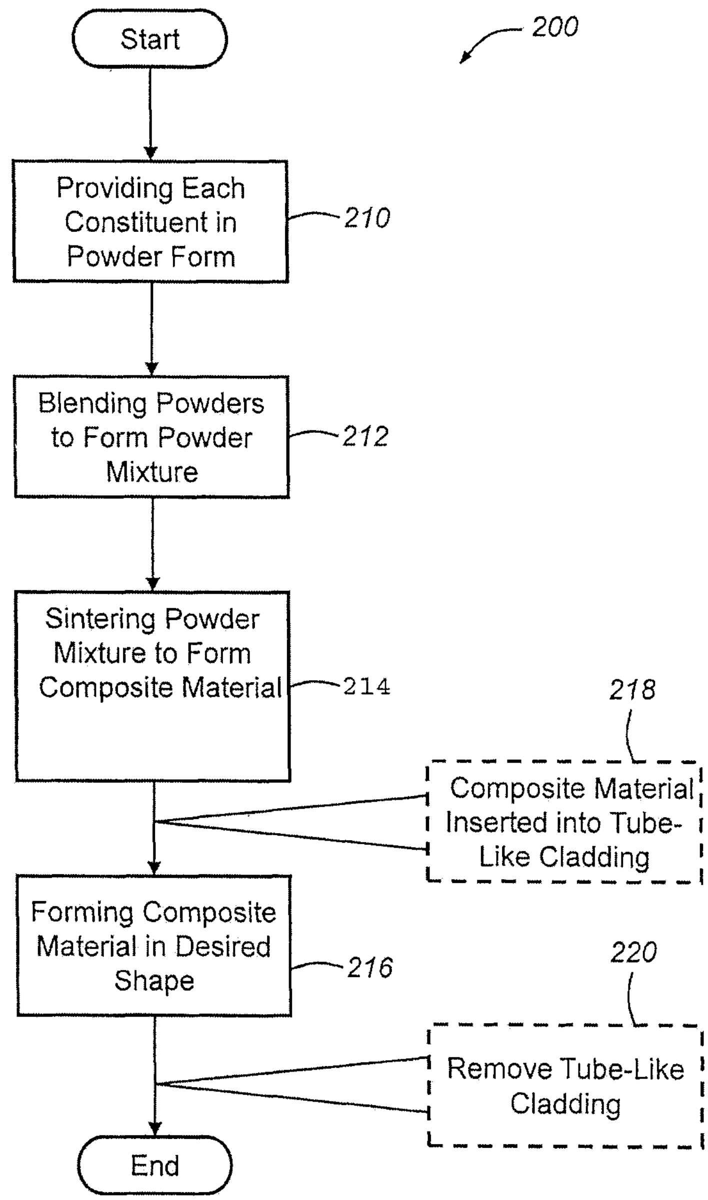

200
Start
Providing Each Constituent in Powder Form
210
Blending Powders to Form Powder Mixture
212
Sintering Powder Mixture to Form Composite Material
214
218
Composite Material Inserted into Tube-Like Cladding
Forming Composite Material in Desired Shape
216
220
Remove Tube-Like Cladding
End

Figure 12

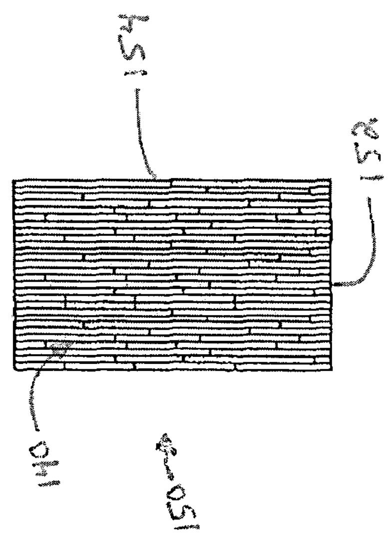


FIG. 15

ELECTRODE MATERIAL FOR A SPARK PLUG

REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Ser. No. 61/671,861 filed on Jul. 16, 2012, the entire contents of which are incorporated herein.

TECHNICAL FIELD

This invention generally relates to spark plugs and other ignition devices for internal combustion engines and, in particular, to electrode materials for spark plugs.

BACKGROUND

Spark plugs can be used to initiate combustion in internal combustion engines. Spark plugs typically ignite a gas, such as an air/fuel mixture, in an engine cylinder or combustion chamber by producing a spark across a spark gap defined between two or more electrodes. Ignition of the gas by the spark causes a combustion reaction in the engine cylinder that is responsible for the power stroke of the engine. The high temperatures, high electrical voltages, rapid repetition of combustion reactions, and the presence of corrosive materials in the combustion gases can create a harsh environment in which the spark plug must function. This harsh environment can contribute to erosion and corrosion of the electrodes that can negatively affect the performance of the spark plug over time, potentially leading to a misfire or some other undesirable condition.

To reduce erosion and corrosion of the spark plug electrodes, various types of precious metals and their alloys—such as those made from platinum and iridium—have been used. These materials, however, can be costly. Thus, spark plug manufacturers sometimes attempt to minimize the amount of precious metals used with an electrode by using such materials only at a firing tip or spark portion of the electrodes where a spark jumps across a spark gap.

SUMMARY

According to one aspect, there is provided a spark plug, comprising: a metallic shell having an axial bore; an insulator having an axial bore and being at least partially disposed within the axial bore of the metallic shell; a center electrode being at least partially disposed within the axial bore of the insulator; and a ground electrode being attached to a free end of the metallic shell. The center electrode, the ground electrode or both includes an electrode material that has a multi-phase composite material with a matrix component and a dispersed component, wherein the matrix component includes at least one precious metal and the dispersed component is embedded in the matrix component and includes at least one item selected from the group consisting of: carbides, nitrides or intermetallics.

According to another aspect, there is provided an electrode material for a spark plug, the electrode material comprising: a multi-phase composite material that includes a matrix component and a dispersed component embedded in the matrix component. The matrix component is a precious-metal based alloy that includes a precious metal as the single largest constituent, and the dispersed component includes at least one of carbides, nitrides, or intermetallics.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred exemplary embodiments of the invention will hereinafter be described in conjunction with the appended drawings, wherein like designations denote like elements, and wherein:

FIG. **1** is a cross-sectional view of an exemplary spark plug that may use the electrode material described below;

FIG. **2** is an enlarged view of the firing end of the exemplary spark plug from FIG. **1**, wherein a center electrode has a firing tip in the form of a multi-piece rivet and a ground electrode has a firing tip in the form of a flat pad;

FIG. **3** is an enlarged view of a firing end of another exemplary spark plug that may use the electrode material described below, wherein the center electrode has a firing tip in the form of a single-piece rivet and the ground electrode has a firing tip in the form of a cylindrical tip;

FIG. **4** is an enlarged view of a firing end of another exemplary spark plug that may use the electrode material described below, wherein the center electrode has a firing tip in the form of a cylindrical tip located in a recess and the ground electrode has no firing tip;

FIG. **5** is an enlarged view of a firing end of another exemplary spark plug that may use the electrode material described below, wherein the center electrode has a firing tip in the form of a cylindrical tip and the ground electrode has a firing tip in the form of a cylindrical tip that extends from an axial end of the ground electrode;

FIG. **6** is a cross-sectional view of an exemplary electrode material that is in the form of a composite material which includes a matrix component and a dispersed component;

FIG. **7** is a schematic representation of a so-called balling and bridging phenomenon at the electrodes of an exemplary spark plug that does not use the electrode material described below;

FIG. **8** is an enlarged schematic representation of the balling and bridging phenomenon of FIG. **7**;

FIG. **9** is a cross-sectional schematic representation of the balling and bridging phenomenon of FIG. **7**;

FIG. **10** is a generalized illustration of a precious-metal based matrix component (without the dispersed component) that has an equiaxed grain structure;

FIG. **11** is a generalized illustration of a precious-metal based matrix component (without the dispersed component) that has a "fibrous" grain structure which includes elongated grains;

FIG. **12** is a flowchart illustrating an exemplary embodiment of a method for forming a spark plug electrode or electrode component;

FIG. **13** is a cross-sectional view of the exemplary electrode material of FIG. **6** in which the electrode material further includes a cladding structure;

FIG. **14** is a cross-sectional view of the exemplary electrode material of FIG. **13** in which the cladding structure is subsequently removed via a chemical etching or other process; and

FIG. **15** is a generalized illustration of an electrode part in which the composite material has the "fibrous" grain structure illustrated in FIG. **11**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The electrode material described herein may be used in spark plugs and other ignition devices including industrial plugs, aviation igniters, glow plugs, or any other device that is used to ignite an air/fuel mixture in an engine. This includes, but is certainly not limited to, the exemplary spark plugs that are shown in the drawings and are described below. Furthermore, it should be appreciated that the electrode material may be used in a firing tip that is attached to a center and/or ground electrode or it may be used in the actual center and/or ground electrode itself, to cite several possibilities. Other embodiments and applications of the electrode material are also possible.

Referring to FIGS. **1** and **2**, there is shown an exemplary spark plug **10** that includes a center electrode **12**, an insulator **14**, a metallic shell **16**, and a ground electrode **18**. The center electrode or base electrode member **12** is disposed within an axial bore of the insulator **14** and includes a firing tip **20** that protrudes beyond a free end **22** of the insulator **14**. The firing tip **20** is a multi-piece rivet that includes a first component **32** made from an erosion- and/or corrosion-resistant material, like the electrode material described below, and a second component **34** made from an intermediary material like a high-chromium nickel alloy. In this particular embodiment, the first component **32** has a cylindrical shape and the second component **34** has a stepped shape that includes a diametrically-enlarged head section and a diametrically-reduced stem section. The first and second components may be attached to one another via a laser weld, a resistance weld, or some other suitable welded or non-welded joint. Insulator **14** is disposed within an axial bore of the metallic shell **16** and is constructed from a material, such as a ceramic material, that is sufficient to electrically insulate the center electrode **12** from the metallic shell **16**. The free end **22** of the insulator **14** may protrude beyond a free end **24** of the metallic shell **16**, as shown, or it may be retracted within the metallic shell **16**. The ground electrode or base electrode member **18** may be constructed according to the conventional L-shape configuration shown in the drawings or according to some other arrangement, and is attached to the free end **24** of the metallic shell **16**. According to this particular embodiment, the ground electrode **18** includes a side surface **26** that opposes the firing tip **20** of the center electrode and has a firing tip **30** attached thereto. The firing tip **30** is in the form of a flat pad and defines a spark gap G with the center electrode firing tip **20** such that they provide sparking surfaces for the emission and reception of electrons across the spark gap.

In this particular embodiment, the first component **32** of the center electrode firing tip **20** and/or the ground electrode firing tip **30** may be made from the electrode material described herein; however, these are not the only applications for the electrode material. For instance, as shown in FIG. **3**, the exemplary center electrode firing tip **40** and/or the ground electrode firing tip **42** may also be made from the electrode material. In this case, the center electrode firing tip **40** is a single-piece rivet and the ground electrode firing tip **42** is a cylindrical tip that extends away from a side surface **26** of the ground electrode by a considerable distance. The electrode material may also be used to form the exemplary center electrode firing tip **50** and/or the ground electrode **18** that is shown in FIG. **4**. In this example, the center electrode firing tip **50** is a cylindrical component that is located in a recess or blind hole **52**, which is formed in the axial end of the center electrode **12**. The spark gap G is formed between a sparking surface of the center electrode firing tip **50** and a side surface **26** of the ground electrode **18**, which also acts as a sparking surface. FIG. **5** shows yet another possible application for the electrode material, where a cylindrical firing tip **60** is attached to an axial end of the center electrode **12** and a cylindrical firing tip **62** is attached to an axial end of the ground electrode **18**. The ground electrode firing tip **62** forms a spark gap G with a side surface of the center electrode firing tip **60**, and is thus a somewhat different firing end configuration than the other exemplary spark plugs shown in the drawings.

Again, it should be appreciated that the non-limiting spark plug embodiments described above are only examples of some of the potential uses for the electrode material, as it may be used or employed in any firing tip, electrode, spark surface or other firing end component that is used in the ignition of an air/fuel mixture in an engine. For instance, the following components may be formed from the electrode material: center and/or ground electrodes; center and/or ground electrode firing tips that are in the shape of rivets, cylinders, bars, columns, wires, balls, mounds, cones, flat pads, disks, rings, sleeves, etc.; center and/or ground electrode firing tips that are attached directly to an electrode or indirectly to an electrode via one or more intermediate, intervening or stress-releasing layers; center and/or ground electrode firing tips that are located within a recess of an electrode, embedded into a surface of an electrode, or are located on an outside of an electrode such as a sleeve or other annular component; or spark plugs having multiple ground electrodes, multiple spark gaps or semi-creeping type spark gaps. These are but a few examples of the possible applications of the electrode material, others exist as well. As used herein, the term "electrode"—whether pertaining to a center electrode, a ground electrode, a spark plug electrode, etc.—may include a base electrode member by itself, a firing tip by itself, or a combination of a base electrode member and one or more firing tips attached thereto, to cite several possibilities.

The electrode material, with reference to the exemplary embodiment illustrated in FIG. **6**, is a multi-phase composite material **100** that includes a matrix component **102** and a dispersed component **104** embedded within the matrix component **102**. The composite material **100** is considered "multi-phase" because the matrix component **102** and the dispersed component **104** are not completely assimilated on a molecular level into a material deemed to be a single composition; rather the two components are separate materials that exhibit some sort of interface or transitional boundary therebetween. The composite material **100** may include anywhere from about 70 vol. % to about 99.9 vol. %—preferably about 98 vol. % to about 99.9 vol. %—of the matrix component **102** and anywhere from about 0.1 vol. % to about 30 vol. %—preferably about 0.1 vol % to about 2.0 vol. %—of the particulate component **104**. Any particular distribution of the dispersed component **104** within the matrix component **102** may be employed. For example, the dispersed component **104** may be homogeneously dispersed throughout the matrix component **102**. In another example, however, a non-homogenous dispersion profile may be employed in which the concentration of the dispersed component **104** in the matrix component **102** differs from one portion of the composite material **100** to another.

The matrix component **102**—also referred to as a matrix phase or binder—is the portion of the composite material **100** into which the dispersed component **104** is embedded. The matrix component **102** is precious metal-based; that is, it includes a precious metal as the single largest constituent on a weight % basis. The designation "precious metal-based" includes, for instance, a material having greater than 50 wt % of a precious metal, as well as a material having less than 50 wt % of a precious metal so long as the precious metal is the single largest constituent on a weight % basis. The matrix component **102** may be a pure precious metal (about 100 wt % precious metal notwithstanding any unavoidable impurities) or an alloy (e.g., binary-, ternary- or quaternary-alloy) including one or more precious metals, or some other suitable precious metal-based material. Preferred precious metals that may be included in the precious-metal based matrix component **102** are platinum (Pt), Iridium (Ir), palladium (Pd), rhodium (Rh), and ruthenium (Ru). A periodic table published by the International Union of Pure and Applied Chemistry (IUPAC) is provided in Addendum A (hereafter the "attached periodic table") and is to be used with the present application.

A precious metal-based material is used as the matrix component **102** because it generally possesses favorable oxidation, corrosion, and erosion resistance when used in ignition environments such as those found in internal combustion engines. But precious metal-based materials may be susceptible to undesirable metallurgical occurrences that can impact the performance of the spark plug in which it is used. Referring to FIGS. **7-9**, for example, some precious metal-based alloys have a tendency to experience a so-called balling and bridging phenomenon in which localized melting and re-deposition of material creates precious metal-based balls B at a surface thereof. This can occur during high temperature operations in an internal combustion engine, and, over time, the precious metal-based balls B can collect and form a bridge across the spark gap G. The ultimate result of balling and bridging is an enhanced rate of erosion (e.g., mass loss and wear) and corrosion of the spark plug electrodes that negatively affects the spark performance of the spark plug. Such balling and bridging can be mitigated or altogether prevented, it has been found, by the inclusion of the dispersed component **104** within the matrix component **102**. Without wishing to be limited to a particular theory of operation, it is currently believed that, among other factors, the combined use of the matrix component **102** and the embedded dispersed component **104** provides the composite material **100** with a surface tension or surface energy that is sufficient to help counteract the balling and bridging phenomenon.

In addition to the precious metal(s), the matrix component **102** may also include other alloy constituents, if desired. One such additional alloy constituent is a refractory metal or a combination of refractory metals. These kinds of metals—which may be present from about 0.1 wt % to 10 wt. % of the matrix component **102**—may provide the composite material **100** with any number of desirable attributes including a high melting temperature and a correspondingly high resistance to spark erosion, as well as improved ductility during manufacturing. Several suitable refractory metals that may be included in the precious metal-based matrix component **102** are rhenium (Re), tungsten (W), tantalum (Ta), molybdenum (Mo), niobium (Nb), or some combination of those metals. It is also possible for the precious metal-based matrix composite **102** to include one or more rare earth metals or active elements. These kinds of metals—which may be present from about 0.001 wt. % to about 0.3 wt. % of the matrix component **102**—may provide the composite material **100** with, for instance, improved resistance to erosion and/or corrosion. Some rare earth metals that may be included in the matrix component **102** are yttrium (Y), hafnium (Hf), scandium (Sc), lanthanum (La), cerium (Ce), and/or other constituents. Besides the single largest precious metal constituent, the precious metal-based matrix component **102** does not necessarily have to include any or all of the types of metals just mentioned (e.g., the refractory metal(s) and the rare earth metal(s)); it may include only one of those types of metals, a combination of two or more of those types of metals, all of those types of metals, or none of those types of metals, as will be appreciated by a skilled artisan.

The matrix component **102** may have an equiaxed grain structure, a fibrous grain structure, or some other desirable grain structure. An equiaxed grain structure **130**, which is shown generally in FIG. **10** (without the dispersed component **104**), includes grains **132** of generally consistent proportions. These grains **132** may have an average grain size that usually ranges from about 1 μm to about 100 μm—preferably less than 20 μm. A "fibrous" grain structure **140**, on the other hand, which is shown in FIG. **11**, comprises elongated grains **142** defined by an axial dimension **142**A and a radial dimension **142**R. The axial dimension **142**A of the grains **142** is generally greater than the radial dimension **142**R by a multiple of two or more, and, typically, six or more (e.g., 82A≥6×82R). The elongated grains **142** are also oriented generally parallel to one another; that is, the axial dimensions **142**A of the grains **142** are generally—but not necessarily exactly—aligned in parallel. Strict parallelism is not required for the elongated grains **142** to be considered generally parallel since it may be difficult, or impractical, to form all the grains **142** with consistent sizes in both the axial **142**A and radial **142**R dimensions, perfectly aligned end-to-end abutments, and perfectly smooth side-by-side interfaces, among others. Some leeway is tolerated so long as the elongated grains **142** as a group have their axial dimensions **142**A extending in the same general direction. The terms "axial dimension" and "radial dimension" are used here to broadly denote the major dimensions of the elongated grains **142**; they are not intended to suggest that the elongated grains **142** are necessarily restricted to being cylindrical in shape.

The dispersed component **104**—also referred to as a dispersed phase or reinforcement—is the portion of the composite material **100** that is embedded in the matrix component **102**. The dispersed component **104** comprises carbides, nitrides, intermetallics, or combinations thereof in the form of any suitable structure such as, for example, particles and/or elongated whiskers or fibers. The size of the particles, fibers, or other structures included in the dispersed component **104** can vary depending on several factors. For example, the particles, if present, may have an average particle size of about 20 μm or less, preferably about 10 μm or less, and the fibers, if present, may have an average diameter of about 20 μm or less, preferably about 10 μm or less, and an aspect ratio that ranges from about 5 to about 50. The elongated fibers, moreover, may be randomly oriented or aligned generally parallel to one another. Embodiments of the composite material **100** in which the matrix component **102** includes a "fibrous microstructure" **140** and the dispersed component **104** includes elongated fibers aligned generally parallel to each other and to the matrix component grains **142** are particularly preferred.

The types of materials chosen for the dispersed component **104** (e.g., carbides, nitrides, intermetallics) generally exhibit high melting points and/or low work functions which, as will be appreciated by skilled artisans, are properties that may be useful in contributing, along with the precious metal-based matrix component **102**, to the operational durability of the composite material **100**. Materials with high melting points, for instance, above about 1100° C., and preferably above about 1600° C., can help improve the spark erosion resistance of the composite material **100** on several fronts. Materials with work functions—an indication of how much energy is needed to extract an electron from the material—below about 6.0 eV, and preferably below about 5.0 eV, are useful keeping the voltage required to initiate sparking as low as possible. Work functions of this magnitude are generally consistent with, and sometimes lower than, the work functions associated with several different precious metals that may be included in the matrix component **102** (see Table 1 below). Materials that exhibit both a high melting point and a low work function can impart both attributes to the composite material **100**.

TABLE 1

Work functions of some precious metals						
Precious Metal	Pt	Ir	Pd	Rh	Ru	Au
Work Function (eV)	5.12-5.93	5.0-5.67	5.22-5.60	4.98	4.71	5.10-5.47

Several specific carbides that may be included in the dispersed component **104** are hafnium carbide (HfC), tungsten carbide (WC), zirconium carbide (ZrC), molybdenum carbide (MoC), chromium carbide (Cr_3C_2, Cr_7C_3, and $Cr_{23}C_6$), niobium carbide (NbC), tantalum carbide (TaC), vanadium carbide (VC), and titanium carbide (TiC), to name but a few examples. Each of these carbides has a high melting point, a high bond energy, a highly chemically inert surface, good electrical conductivity, and a low work function. The melting points and work functions of several of the more preferred carbides are detailed below in Table 2.

TABLE 2

Properties of some select carbides						
Particles	VC	Cr_3C_2	NbC	HfC	TaC	WC
Work Function (eV)	5.15	5.10-5.20	4.85-4.95	4.80-4.90	4.90	4.90
Melting Point (° C.)	2810	1895	3490	3305	3880	2870

Several specific nitrides that may be included in the dispersed component **104** are hafnium nitride (HfN), tungsten nitride (WN), zirconium nitride (ZrN), molybdenum nitride (MoN), chromium nitride (CrN), niobium nitride (NbN), tantalum nitride (TaN), vanadium nitride (VN), titanium nitride (TiN), titanium carbo-nitride (TiCN), titanium aluminum nitride (TiAlN), and titanium aluminum carbo-nitride (TiAlCN), to name but a few examples. And much like the carbides previously discussed, each of these nitrides has a high melting point, a high bond energy, a highly chemically inert surface, good electrical conductivity, and a low work function. The melting points and work functions of several of the more preferred nitrides are detailed below in Table 3.

TABLE 3

Properties of some select nitrides						
Particles	TiN	HfN	TaN	NbN	VN	TiAlN
Work Function (eV)	5.05-5.15	4.70-4.80	4.70-4.80	4.95	5.05-5.15	—
Melting Point (° C.)	2930	3305	3090	2573	2050	2930

Several specific intermetallics that may be included in the dispersed component **104** are RuAl, NiAl, Pt_3Al, TiAl, Fe_2Al_5, $NbAl_3$, $MoSi_2$, RuTi, $NbPt_3$, to name but a few examples. These and other intermetallics are solid-state metallic phase materials in which the elemental metal constituents are present in stoichiometrically fixed proportions and generally defined crystal lattice locations. The melting points of several of the more preferred intermetallics are detailed below in Table 4.

TABLE 4

Properties of some select intermetallics								
Particles	RuAl	NiAl	Pt3Al	TiAl	Fe2Al5	NbAl3	MoSi2	RuTi
Melting Point (° C.)	2050	1638	1554	1500	1169	1680	2020	2130

The inclusion of dispersed component **104** in the matrix component **102** can have several effects on the properties of the composite material **100**. For example, the addition of dispersed component **104** may increase the surface tension and/or the melting temperature of the composite material **100** in comparison to the same material without the dispersed component **104**. The dispersed component **104**—due to its relatively low work function—may also attract sparking away from the matrix component **102** so that localized temperatures of the matrix component **102** exposed at the sparking surface do not increase as quickly during sustained high-temperature spark plug operating events. Affecting the composite material **100** in this way enhances the corrosion and erosion resistance the composite material **100** when used in spark plug applications by, among other mechanisms, mitigating the balling and bridging phenomenon described above with reference to FIGS. **7-9**. Furthermore, the dispersed component **104** generally reduces the overall cost of the composite material **100** because carbides, nitrides, and intermetallics typically cost less than the precious metals that are included in the matrix component **102**.

The following embodiments recite different composite materials **100** materials from which any of the electrodes or electrode components shown in FIGS. **1-5**, as well as others not specifically shown, may be constructed. These composite materials **100** are preferably used to construct the firing tip component **32** of the center electrode **12** and/or the firing tip **30** of the ground electrode **18**, as depicted in FIG. **2**, as well as the other center electrode firing tips **40**, **50**, **60** and ground electrode firing tips **42**, **62** shown in FIGS. **3-5**. These exemplary composite materials **100** are not meant to be an exhaustive list of all such embodiments, however, as others are certainly possible. It should be appreciated that any number of other constituents may be added to the following embodiments.

According to one embodiment, the matrix component **102** of the composite material **100** is platinum-based; that is, the single largest constituent of the matrix component **102** is platinum. The platinum-based matrix component **102** may, for example, be pure platinum (100 wt. % Pt notwithstanding unavoidable impurities) or a platinum alloy having nickel, tungsten, or iridium as the second largest constituent. Suitable platinum alloys that may be employed include (the following alloys are given in weight percentage, and the Pt constitutes the balance) Pt-(1-20)Ni, Pt-(1-10)Ni, Pt-(1-10) W, Pt-(1-5)W, Pt-(1-20)Ir, Pt-(1-10)Ir, Pt-(1-40)Pd, Pt-(1-30) Pd, Pt-(1-20)Pt, and Pt-(1-10)Pd. Some specific and preferred platinum alloys that may be used to construct the platinum-based matrix component **102** are Pt, Pt-10Ir, Pt-10Ni, and Pt-4W. Any of a wide variety of other platinum-based alloys may be used as well despite not being specifically mentioned here.

The dispersed component **104** embedded in the platinum-based matrix component **102** is preferably selected from the following lists of carbides, nitrides, and intermetallics: HfC, WC, ZrC, MoC, $Cr_{23}C_6$, Cr_3C_2, NbC, TaC, VC, TiC, HfN, WN, ZrN, MoN, CrN, NbN, TaN, VN, TiN, TiCN, TiAlN, TiAlCN, RuAl, NiAl, Pt_3Al, TiAl, Fe_2Al_5, $NbAl_3$, $MoSi_2$, RuTi, and $NbPt_3$. Some specific and preferred composite materials **100** that include a platinum metal-based material matrix **102** and a dispersed phased **104** that includes the materials listed above are (the following alloys are given in weight percentage, and the Pt constitutes the balance) Pt-(0.1-2.0)HfC, Pt-(0.1-2.0)WC, Pt-(0.1-2.0)NbC, Pt-(0.1-2.0)TaC, Pt-(0.1-2.0)HfN, Pt-(0.1-2.0)NbN, Pt-(0.1-2.0)TaN, Pt-(0.1-2.0)RuAl, Pt-(0.1-2.0)$MoSi_2$, and Pt-(0.1-2.0)RuTi.

It should be appreciated that the preceding embodiments represent only some of the possible combinations of the matrix component **102** and the dispersed component **104** that may be employed to form the composite material **100**. For example, other precious metal-based materials may be used for the matrix component **102**, and other carbides, nitrides, and/or intermetallics may be included in the dispersed component **104**.

Turning now to FIG. **12**, the composite material **100** can be made and formed into an appropriate shape using a variety of manufacturing processes. For instance, a powder metallurgy process **200** may be used that includes the steps of: providing each of the constituents in powder form, step **210**; blending the powders together to form a powder mixture, step **212**; sintering the powder mixture to form the composite material **100**, step **214**; and forming the composite material **100** into a desired shape, step **216**. The process may further include one or more optional steps that provide a cladding or sheath around the composite material **100** to make it more workable.

In step **210**, the different constituents of the precious metal-based matrix component **102** and the dispersed component **104** are provided in powder form at appropriate powder or particle sizes that may be dependent on a number of factors. According to one exemplary embodiment, the constituents of the matrix component **102** and the dispersed component **104** are individually provided in powder form with each of the constituents having a particle size ranging from about 0.1 μm to about 200 μm or a diameter and aspect ratio ranging from about 0.2 μm to about 25 μm and about 0.5 to about 20, respectively. The sizes of the dispersed component **104** constituents may, in some instances, be larger than the expected sizes of the particles of fibers that constitute the dispersed component **104** to account for particle size reductions or elongation (fibers) that may occur during the forming step **216**. In another embodiment, the constituents of the matrix component **102** are pre-alloyed and formed into a base matrix powder before being mixed with the constituents of the dispersed component **104**.

Next, in step **212**, the powders are blended together to form a powder mixture. In one embodiment, for example, the powder mixture includes enough of the matrix component **102** constituents and enough of the dispersed component **104** constituents so that the resultant composite material **100** comprises, depending on the particular composition of the composite material **100** desired, anywhere from about 70 vol. % to about 99.9 vol % of the matrix component **102** and anywhere from about 0.1 vol. % to about 30 vol. % of the particulate component **104**. This mixing step may be performed with or without the addition of heat.

The sintering step **214** transforms the powder mixture into the composite material **100** through the application of heat. The sintering step **214** may be performed according to a number of different metallurgical embodiments. For instance, the powder mixture may be sintered in a vacuum, in a reduction atmosphere such as in a hydrogen-contained environment, or in some type of protected environment for up to several hours at an appropriate sintering temperature. Oftentimes an appropriate sintering temperature lies somewhere in the range of about 1200° C. to about 1700° C. for the precious metal-based powder constituents which form the matrix component **102**. It is also possible for the sintering step **214** to apply pressure in order to introduce some type of porosity control. The amount of pressure applied may depend on the precise composition of the powder mixture and the desired attributes of the composite material **100**. The composite material **100** that results following the sintering step **214** is preferably shaped as a bar or other.

Next, in step **216**, the composite material **100** is formed into a desired shape by any known process or combination of processes such as, for example, rolling swaging, drawing, extrusion, annealing, or any other suitable technique. If an elongated wire is ultimately desired, then the composite material **100** bar derived from the sintering step **214** may be hot-swaged followed by repeated hot-drawing and intermittent annealing until an elongated fine wire of about 0.3 mm to about 1.5 mm in diameter is obtained. Repeated hot-drawing and intermittent annealing of the composite material **100** below its recrystallization temperatures may be practiced, for example, if the "fibrous" grain structure **140** described in FIG. **11** is desired. The elongated fine wire may then be cut or otherwise cross-sectioned into individual electrode tips or the like. Of course, other metal forming techniques could be used with step **216** to form the composite material **100** into parts having different shapes. For example, the composite material **100** could be forged, cast, or otherwise formed into ingots, bars, rivets, tips, etc.

With brief reference to FIG. **15** for the moment, if the composite material **100** includes a "fibrous" grain structure **140**, then a useable part **150** derived from the composite material elongated wire or other structure is preferably employed in any of the spark plugs shown in FIGS. **1-5** so that a surface **152** of the part **150** normal to the axial dimensions **142**A of the grains **142** (hereafter "normal surface **152**" for brevity) constitutes the sparking surface. Such an orientation of the part **150** within the spark plug **10** may result in the axial dimensions **142**A of the elongated grains **142** (and the fibers in the dispersed component **104** if present) lying parallel to a longitudinal axis L_C of the center electrode **12** (FIG. **2**) if the part **150** is attached to the center electrode **12** or the ground electrode **18**. For example, if the part **150** is used as the firing tip **32** for the multi-layer rivet (MLR) design shown in FIGS. **1-2**, the normal surface **152** preferably faces the firing tip **30** attached to the ground electrode **18**. In doing so, the axial dimensions **142**A of the grains **142** lie parallel to the longitudinal axis L_C of the center electrode **12** and perpendicular to the sparking surface of the firing tip **32**. The part **150** is also preferably used in the same way for the other firing tip components **40**, **50**, shown in FIGS. **3-4**. Likewise, as another example, if the part **150** is used as a firing tip **30**, **42** attached to the ground electrode **18** in the designs shown in FIGS. **1-3**, the normal surface **152** preferably faces the firing tip **32**, **40** attached to the center electrode **12**. In these embodiments, the axial dimensions **142**A of the grains **142** lie parallel to the longitudinal axis L_C of the center electrode **12**, as before, and perpendicular to the sparking surface of the firing tip **32**. Using another surface of the part **150**—besides the normal surface **152**—as the sparking surface, although not as preferred, may still be practiced. For example, if the part **105** is used as the firing tip **60** for the design shown in FIG. **5**, the normal surface **152** may not face the firing tip **62** attached to the ground electrode **18**; instead, a side surface **154** may face the firing tip **62** and act as the sparking surface.

As mentioned above, it is also possible for method **200** to include an optional step in which the composite material **100** is formed with a cladding or sheath made of a different material, so that the combined electrode material and cladding can be formed during step **216**. In one embodiment, an additional step **218** is provided where the already sintered composite material **100** from step **214** is inserted into a tube-like cladding structure **106**, as illustrated in FIG. **13**. The cladding structure **106** may be precious metal-based, nickel-based, copper-based, or zinc-based, for example. In the event that cladding structure **106** is precious metal-based, the cladding or sheathing may include pure platinum (Pt), pure palladium (Pd), pure gold (Au), pure silver (Ag) or some alloy thereof. In the example of a copper-based cladding structure, oxygen-free copper (Cu) is an acceptable choice. Zinc-based cladding structures may be used when a relatively high degree of lubrication is desired during the forming process. Other cladding materials are also possible, of course, even though not explicitly recited here. A cladding structure **106** having a cladding wall thickness of about 150 μm to about 3 mm may be used.

In the exemplary cladding examples described above, once the composite material **100** and cladding structure **106** have been co-formed, the cladding structure **106** may be removed by chemical etching, mechanical measures, or some other suitable technique in optional step **220**. This process is illustrated in FIG. **14**. In these examples, the cladding structure **106** is used to facilitate the forming process, step **216**, but is removed thereafter so that the resulting composite material **100** can be formed into a spark plug electrode or electrode component without any cladding.

The above-described processes may be used to form the composite material **100** into various shapes (such as rods, wires, sheets, etc.) that are suitable for further spark plug electrode and/or firing tip manufacturing processes. Other known techniques such as melting and blending the desired amounts of each constituent may be used in addition to or in lieu of those steps mentioned above. The composite material **100** can be further processed using conventional cutting and grinding techniques that are sometimes difficult to use with other known erosion-resistant electrode materials.

It is to be understood that the foregoing is a description of one or more preferred exemplary embodiments of the invention. The invention is not limited to the particular embodiment(s) disclosed herein, but rather is defined solely by the claims below. Furthermore, the statements contained in the foregoing description relate to particular embodiments and are not to be construed as limitations on the scope of the invention or on the definition of terms used in the claims, except where a term or phrase is expressly defined above. Various other embodiments and various changes and modifications to the disclosed embodiment(s) will become apparent to those skilled in the art. All such other embodiments, changes, and modifications are intended to come within the scope of the appended claims.

As used in this specification and claims, the terms "for example," "e.g.," "for instance," "such as," and "like," and the verbs "comprising," "having," "including," and their other verb forms, when used in conjunction with a listing of one or more components or other items, are each to be construed as open-ended, meaning that that the listing is not to be considered as excluding other, additional components or items. Other terms are to be construed using their broadest reasonable meaning unless they are used in a context that requires a different interpretation.

The invention claimed is:

1. A spark plug, comprising: a metallic shell having an axial bore; an insulator having an axial bore and being at least partially disposed within the axial bore of the metallic shell; a center electrode being at least partially disposed within the axial bore of the insulator; and a ground electrode being attached to a free end of the metallic shell; the center electrode, the ground electrode or both includes an electrode material that has a multi-phase composite material with a matrix component and a dispersed component, wherein the matrix component includes at least one precious metal, a transition metal, and a rare earth metal, and the dispersed component is an intermetallic embedded in the matrix component, and wherein the matrix component includes about 0.001 wt % to 0.3 wt % of the rare earth metal.

2. The spark plug of claim **1**, wherein the matrix component includes about 90 wt % to 99.9 wt % of the at least one precious metal.

3. The spark plug of claim **1**, wherein the matrix component includes at least one precious metal selected from the group consisting of: platinum (Pt), Iridium (Ir), palladium (Pd), rhodium (Rh) or ruthenium (Ru).

4. The spark plug of claim **3**, wherein the matrix is a platinum-based alloy and is selected from the group consisting of: Pt—Ni, Pt—W, Pt—Ir or Pt—Pd.

5. The spark plug of claim **1**, wherein the matrix component includes about 0.1 wt % to 10 wt % of the transition metal.

6. The spark plug of claim **1**, wherein the matrix component includes at least one transition metal selected from the group consisting of: rhenium (Re), tungsten (W), tantalum (Ta), molybdenum (Mo) or niobium (Nb).

7. The spark plug of claim **1**, wherein the multi-phase composite material includes about 70 vol % to about 99.9 vol % of the matrix component and about 0.1 vol % to about 30 vol % of the dispersed component.

8. The spark plug of claim **1**, wherein the matrix component includes at least one rare earth metal selected from the group consisting of: yttrium (Y), hafnium (Hf), scandium (Sc), lanthanum (La) or cerium (Ce).

9. The spark plug of claim **1**, wherein the dispersed component includes at least one intermetallic selected from the group consisting of: ruthenium aluminum (RuA**1**), nickel aluminum (NiAl), platinum aluminum (Pt_3Al), titanium aluminum (TiAl), iron aluminum (Fe_2Al_5), niobium aluminum ($NbAl_3$), molybdenum silicon ($MoSi_2$), ruthenium titanium (RuTi) or niobium platinum ($NbPt_3$).

10. The spark plug of claim **1**, wherein the dispersed component has a melting point above about 1100° C. and a work function below about 6.0 eV.

11. The spark plug of claim **1**, wherein the dispersed component has a fibrous microstructure with elongated fibers or whiskers that are generally aligned parallel to each other and to grains of the precious metal-based matrix component and have an average diameter of about 20 μm or less.

12. The spark plug of claim **1**, wherein the multi-phase composite material includes at least one of the following matrix component-dispersed component combinations, where the materials are given in weight percentage ranges and Pt constitutes the balance: Pt-(0.1-2.0)RuAl, Pt-(0.1-2.0)$MoSi_2$ or Pt-(0.1-2.0)RuTi.

13. The spark plug of claim **1**, wherein the center electrode, the ground electrode or both includes a separate firing tip that is made from the multi-phase composite material and is attached to the center electrode, the ground electrode or both via welding.

14. An electrode material for a spark plug, the electrode material comprising:

a multi-phase composite material that includes a matrix component and a separate dispersed component embedded in the matrix component, the matrix component is a precious-metal based alloy that includes a precious metal as the single largest constituent of the matrix component, a transition metal as the second largest constituent of the matrix component, and a rare earth metal as the third largest constituent of the matrix component, and the dispersed component includes at least one of carbides, nitrides, or intermetallics.

15. A spark plug, comprising:

a metallic shell having an axial bore;

an insulator having an axial bore and being at least partially disposed within the axial bore of the metallic shell;

a center electrode being at least partially disposed within the axial bore of the insulator; and

a ground electrode being attached to a free end of the metallic shell;

the center electrode, the ground electrode or both includes an electrode material that has a multi-phase composite material with a matrix component and a dispersed component, wherein the matrix component includes at least one precious metal and the dispersed component includes a carbide or a nitride that is embedded in the matrix component so that the matrix component and the dispersed component are separate materials that exhibit an interface or transitional boundary therebetween.

16. The spark plug of claim **15**, wherein the dispersed component includes at least one carbide selected from the group consisting of: hafnium carbide (HfC), tungsten carbide (WC), zirconium carbide (ZrC), molybdenum carbide (MoC), chromium carbide (Cr_3C_2, Cr_7C_3, $Cr_{23}C_6$), niobium carbide (NbC), tantalum carbide (TaC), vanadium carbide (VC) or titanium carbide (TiC).

17. The spark plug of claim **15**, wherein the dispersed component includes at least one nitride selected from the group consisting of: hafnium nitride (HfN), tungsten nitride (WN), zirconium nitride (ZrN), molybdenum nitride (MoN), chromium nitride (CrN), niobium nitride (NbN), tantalum nitride (TaN), vanadium nitride (VN), titanium nitride (TiN), titanium carbo-nitride (TiCN), titanium aluminum nitride (TiAlN) or titanium aluminum carbo-nitride (TiAlCN).

18. The spark plug of claim **15**, wherein the matrix component includes platinum or a platinum alloy, at least one transition metal, and at least one rare earth metal, and the platinum or the platinum alloy is the single largest constituent of the matrix component.

19. The spark plug of claim **15**, wherein the multi-phase composite material includes at least one of the following matrix component-dispersed component combinations, where the materials are given in weight percentage ranges and Pt constitutes the balance: Pt-(0.1-2.0)HfC, Pt-(0.1-2.0)WC, Pt-(0.1-2.0)NbC, Pt-(0.1-2.0)TaC, Pt-(0.1-2.0)HfN, Pt-(0.1-2.0)NbN, or Pt-(0.1-2.0)TaN.

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